Hydrodynamic Processes in the Delta: Some things that might be important and probably are tricky to model

Stephen G. Monismith
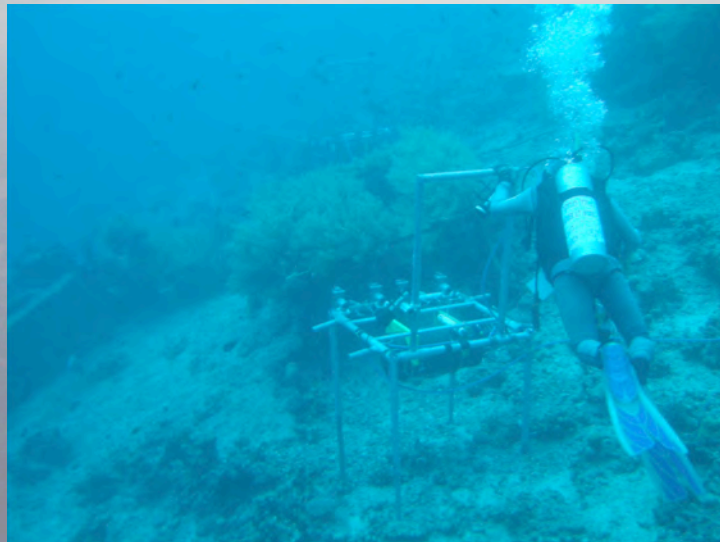
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# Studying biophysical coupling in the Gulf of Aqaba (Eilat)

Outline

- Bathymetry and roughness: Differential friction in Threemile Slough
- Role of dispersion in setting water temperature: The Stockton Ship Channel
- The effect of diurnal stratification on turbulence: The Stockton Ship Channel
- The effect of channel junctions on particle transport: Modeling with a version of the DSM2-PTM
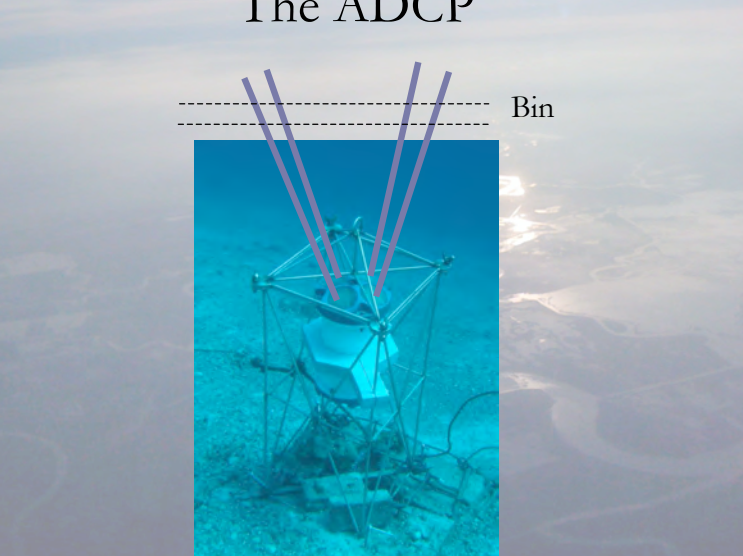
Typical Delta Stakeholder

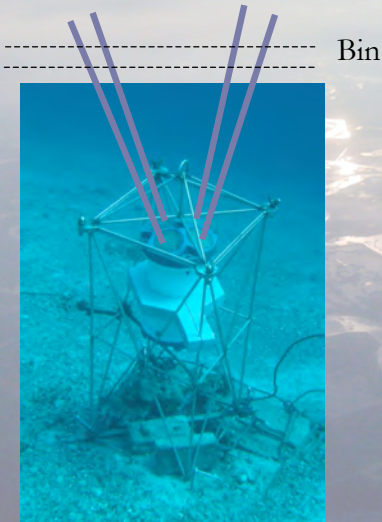Threemile Slough 2002 - goal: examine effects of curvature on flow structure

Primary flow
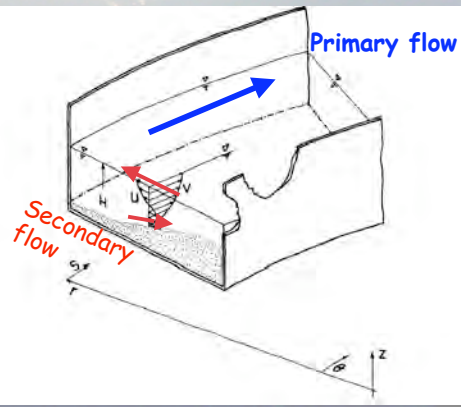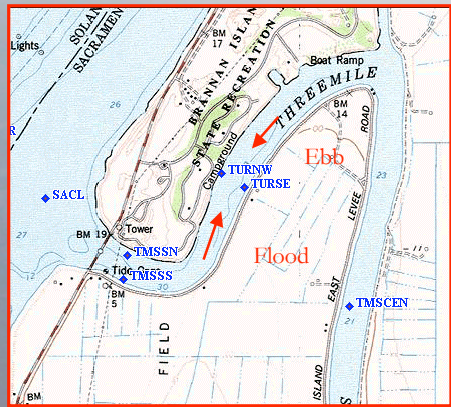
Secondary flow

Fong et al, *J. Hydraulic Engineering,* 2009

The ADCP

Bin

(Gulf of Aqaba Feb 2011)

Results: Mean Currents

Alongchannel Currents [cm/s]
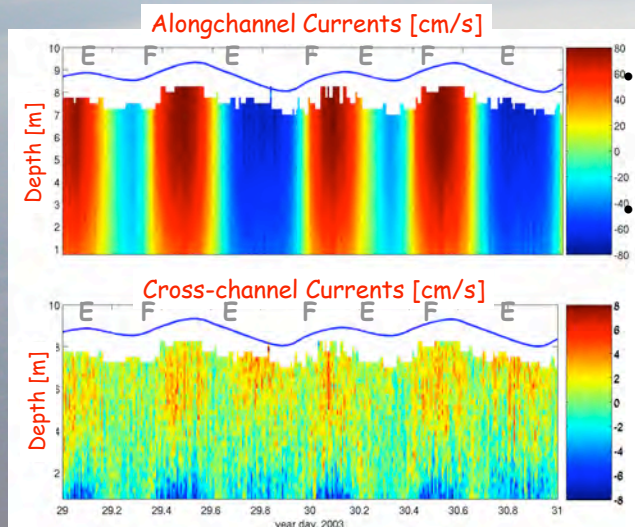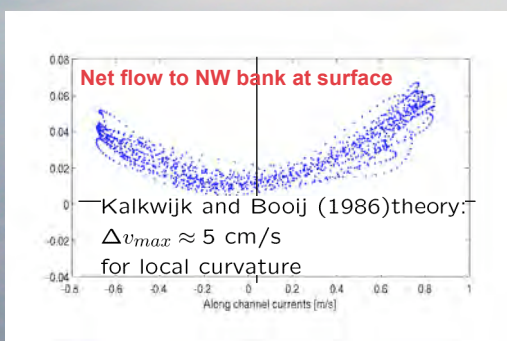

- Strong diurnal / semi-diurnal tidal signal
- Noticeable secondary circulation for flood and ebb.

Δv

Results: Secondary currents

Net flow to NW bank at surface

Kalkwijk and Booij (1986) theory:
$\Delta v_{max} \approx 5$ cm/s
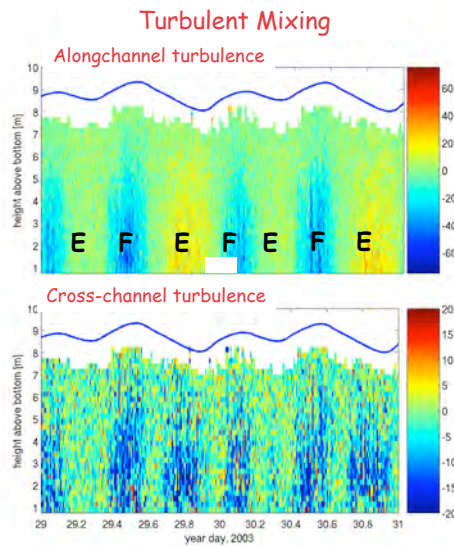for local curvature

Secondary currents the same sense for both flood and ebb:

Secondary currents not driven by major bends, but dominated by local curvature

Results: Turbulent stresses

Turbulent Mixing

Alongchannel turbulence

Cross-channel turbulence

- Turbulent stresses done using single ping ADCP data with variance technique
- Enhanced turbulence for both flood and ebb currents.
- Turbulence highest in lower portion of water column: consistent with bottom generated turbulence.

Results: Stresses / C_d: Drag coefficients

SE ADCP

Ebb:
C_d =0.004

Flood:
C_d =0.0154
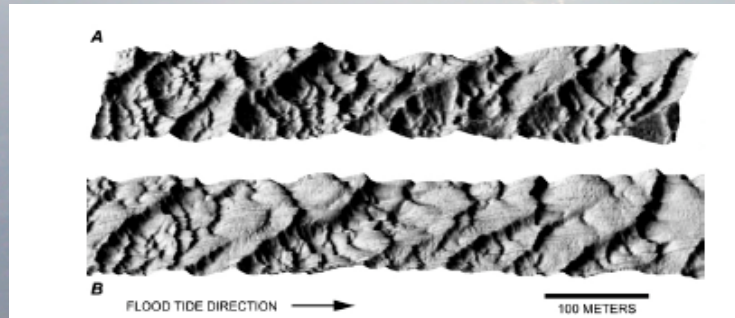
NW ADCP

Ebb:
C_d =0.004
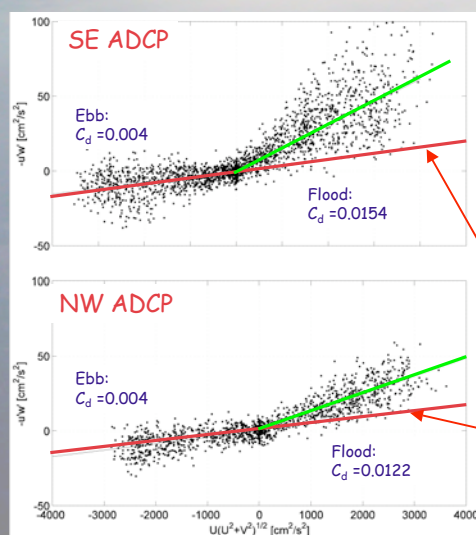
Flood:
C_d =0.0122

– Higher drag coefficient for flood tide.
– Asymmetric drag measured at both sites.

Most models assuming a constant drag coefficient!

Results: interpretation / explanation

<u>Hypothesis</u>: Bedforms are likely responsible for asymmetric drag. (consistent with streamlining theory)


A

B

FLOOD TIDE DIRECTION ⟶   100 METERS

Bedforms in 3MS are 20-30% the total water depth! (Dinehart 2002)
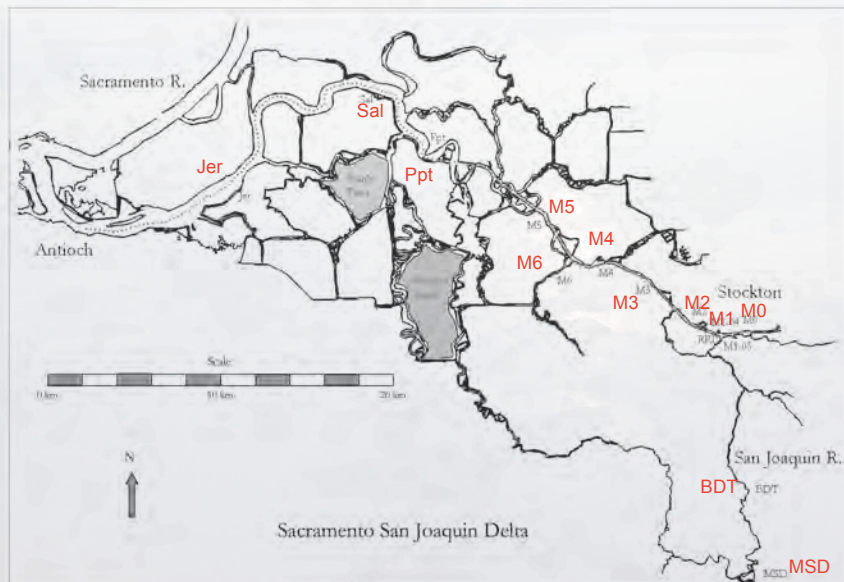

Why this might be tricky to model

- Direction-dependent drag coefficient is not the norm for 3D models
- Bedforms and hence drag change in time

2004/05 Stanford/Davis/USGS DWSC study

Develop a 3D model of low DO in the DWSC based on
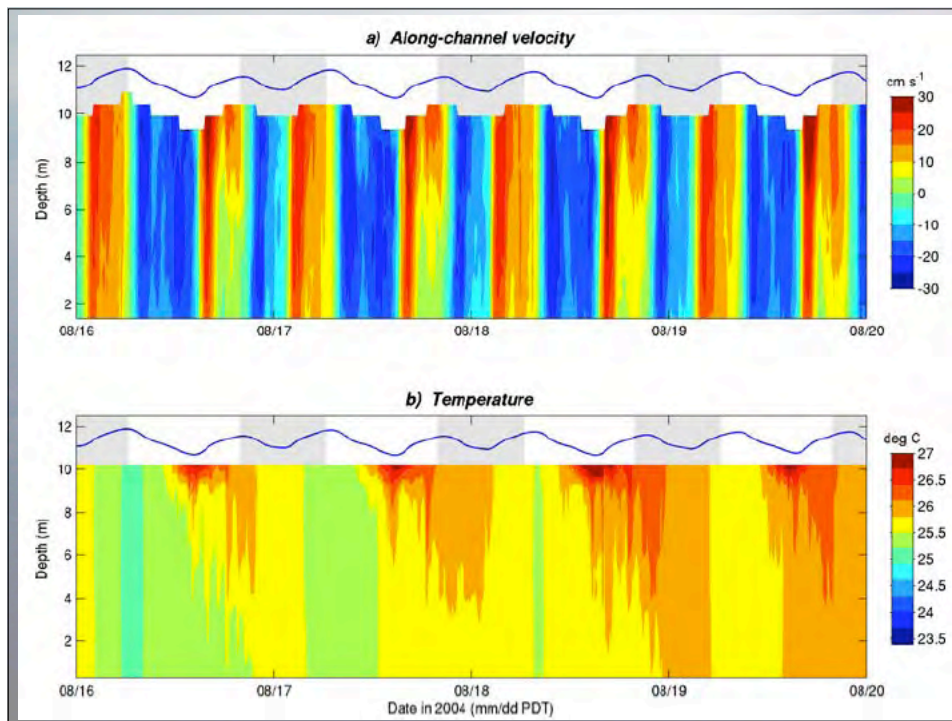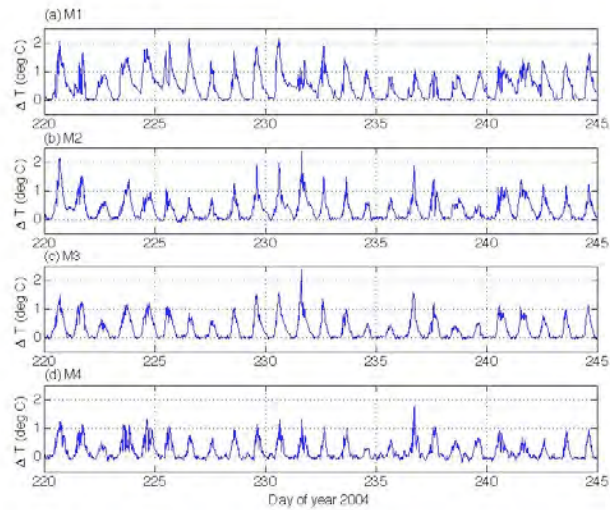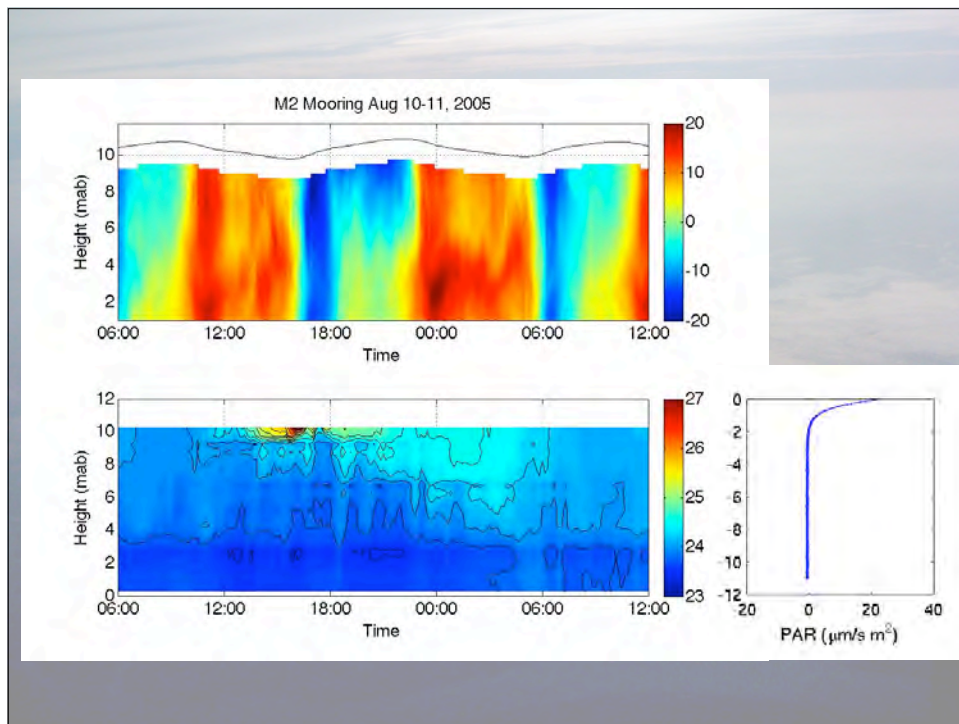(a) Data and (b) Understanding of how physics works
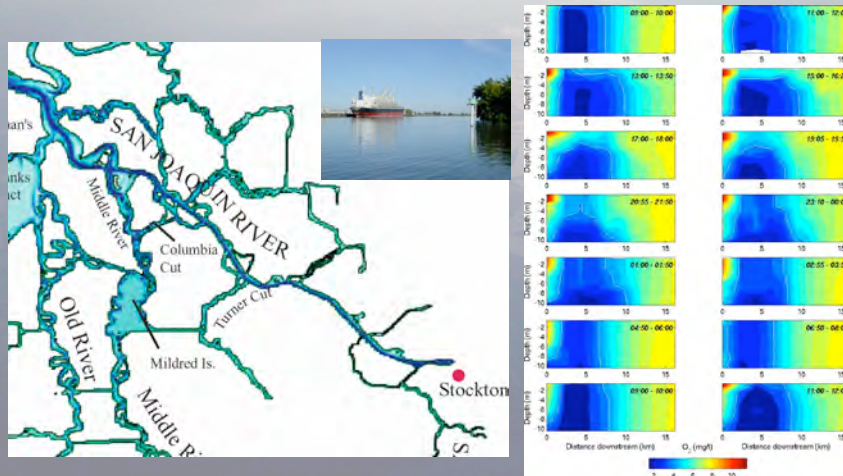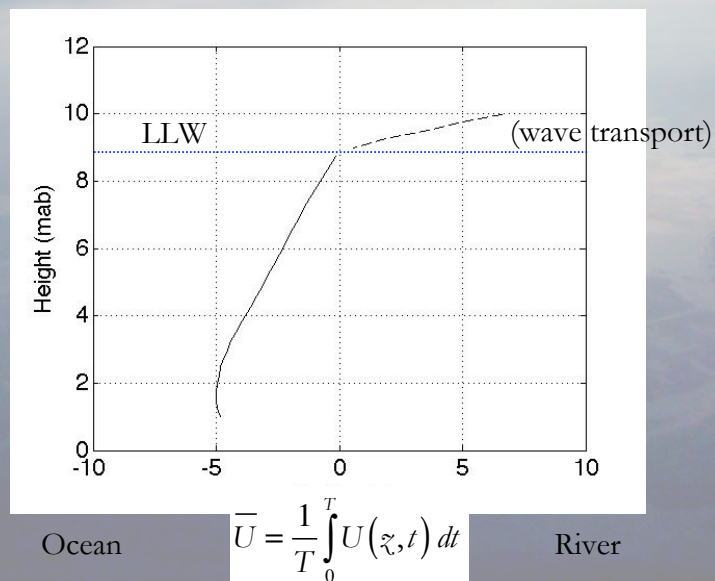

2004/05 Stanford/Davis/USGS DWSC study

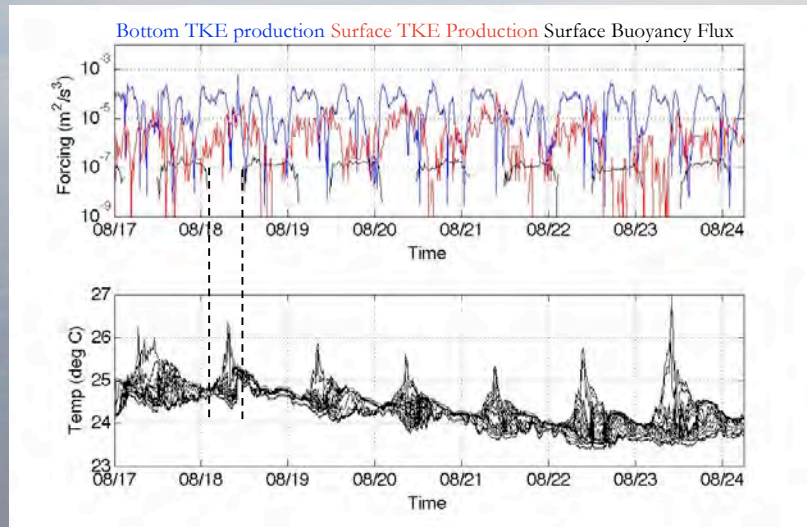Temperature stations 2004/05

Stratification

Interesting outcome..

LLW   (wave transport)
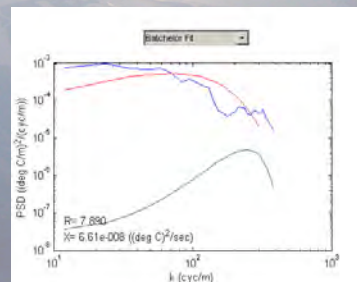
Ocean $\overline{U} = \dfrac{1}{T}\displaystyle\int_0^T U(z,t)\,dt$ River
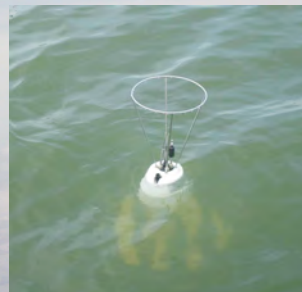
Energetics of stratification?

Bottom TKE production Surface TKE Production Surface Buoyancy Flux

SCAMP

- Measures 1mm vertical scale variations in Temp,etc. Chl*a* fluorescence, obs turbidity,…
- Rises *freely* at 10 cm/s independent
- Small scale temperature variations used to infer turbulence dissipation

San Joaquin River, 16 August 2004, 15:28

M2 Mooring Aug 23-24, 2005

$$Fr_t = \left(\frac{L_c}{L_o} \right)^{2/3}$$

Thorpe Scale (m)

Ozmidov Scale (m)

Thorpe scale ≈ Turbulent eddy size
Ozmidov scale = largest eddy in presence of stratification
Max length scale no stratification ≈ 1.2 m

$$Fr_t = \left(\frac{L_c}{L_o}\right)^{2/3}$$

Decreasing buoyancy effects

strong buoyancy

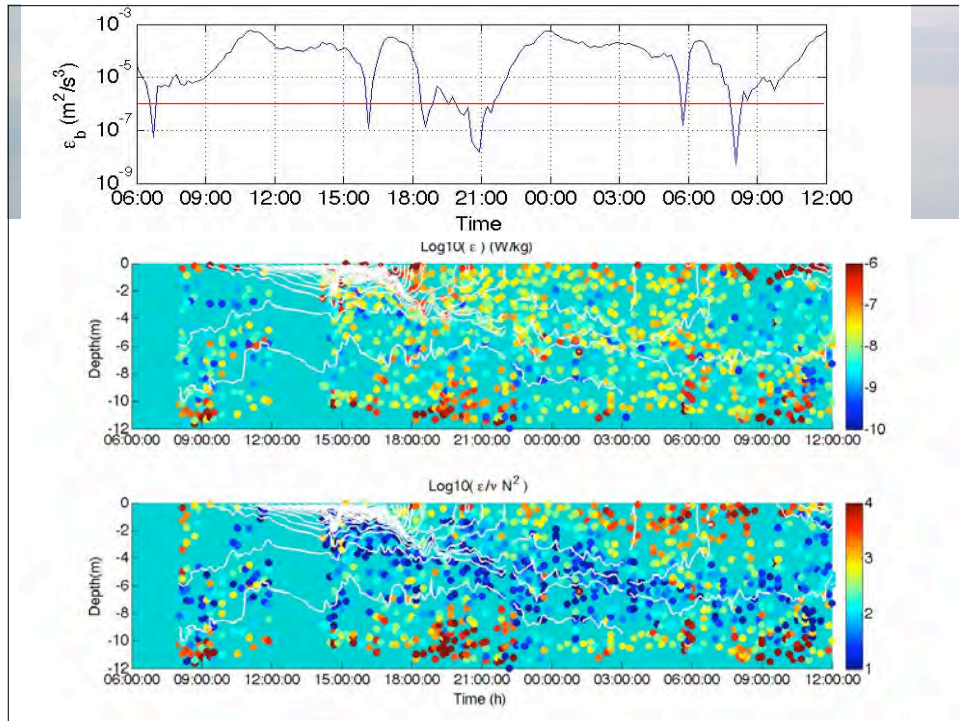$$\frac{\varepsilon}{\nu N^2} \approx 10$$

IV
Dead

III
Fossil/Dead

$$Re_t = \left(\frac{L_c}{L_K}\right)^{4/3}$$
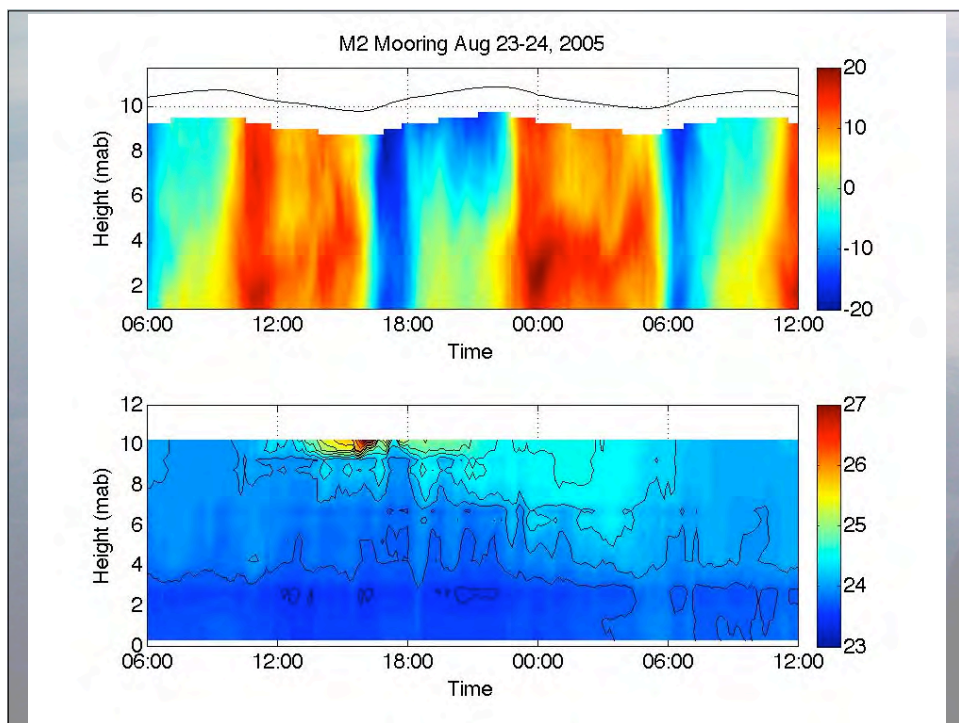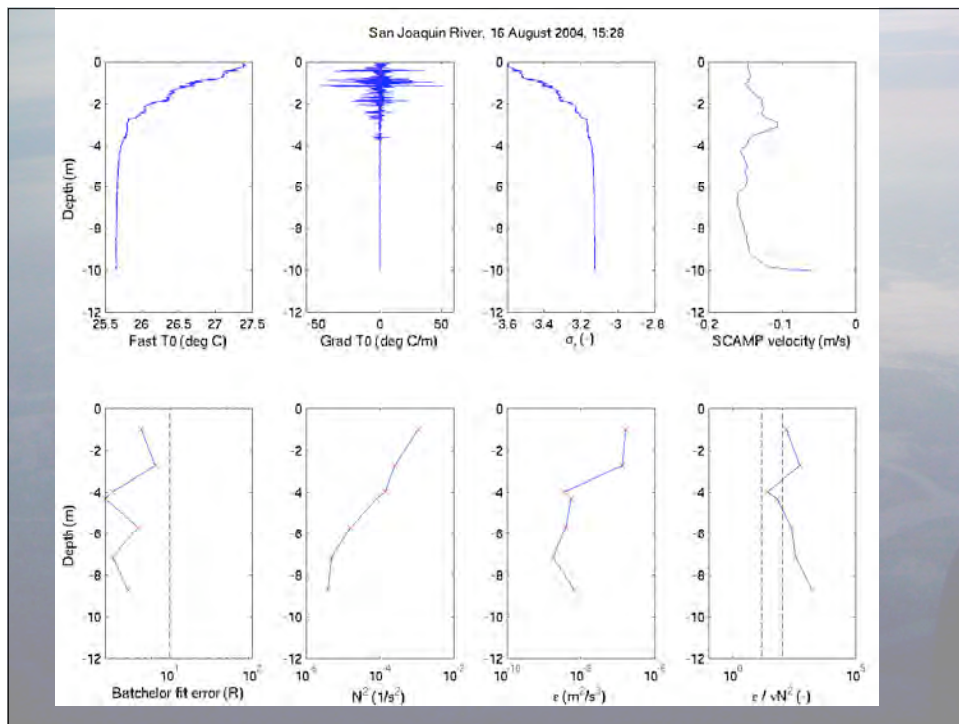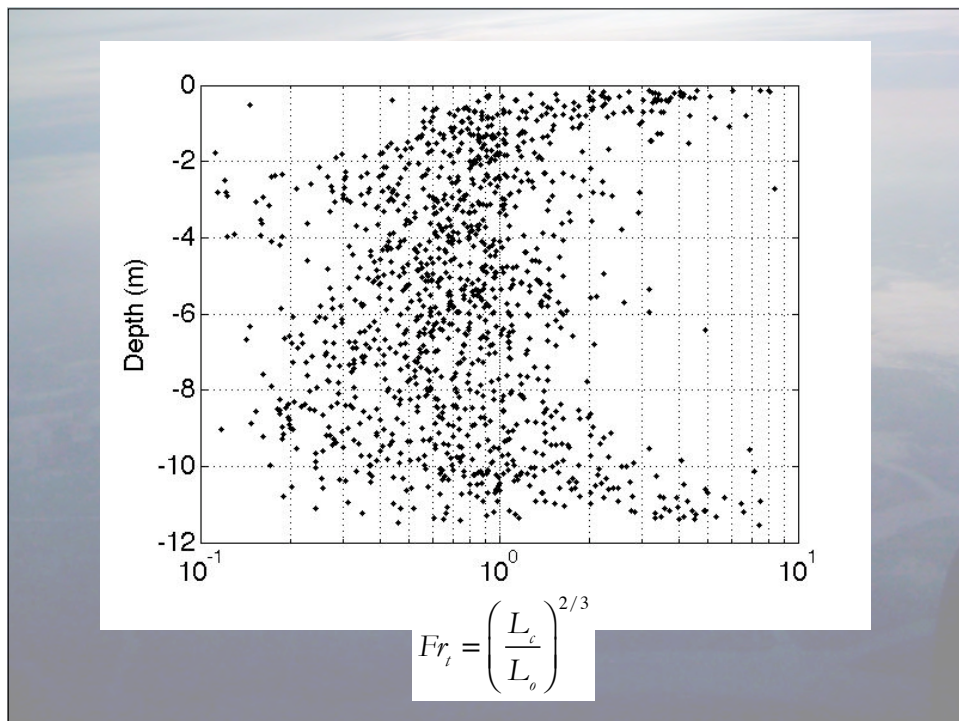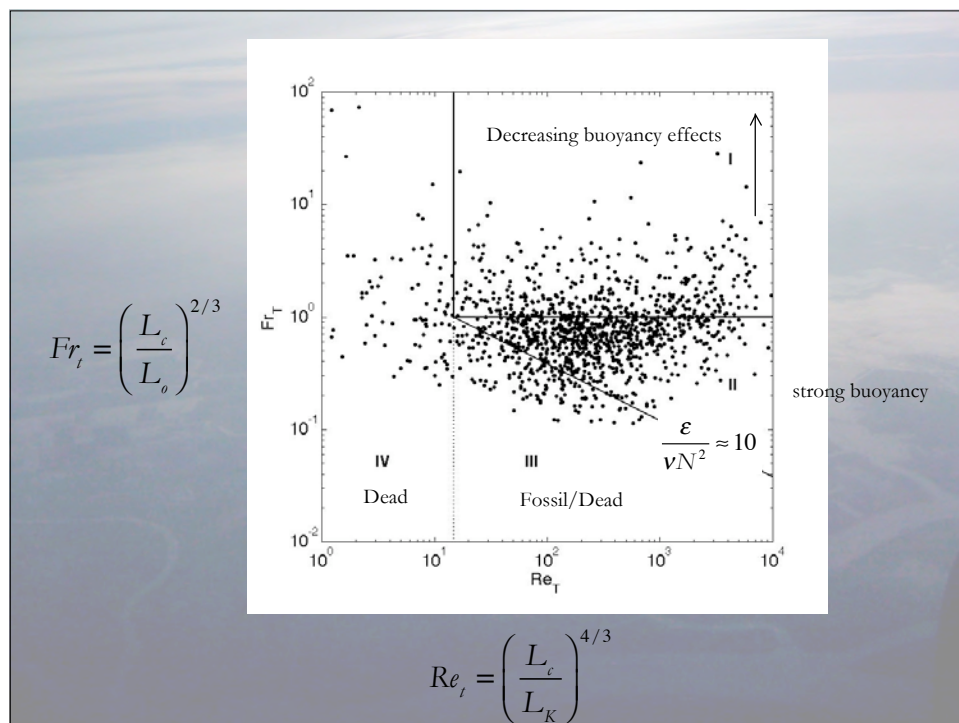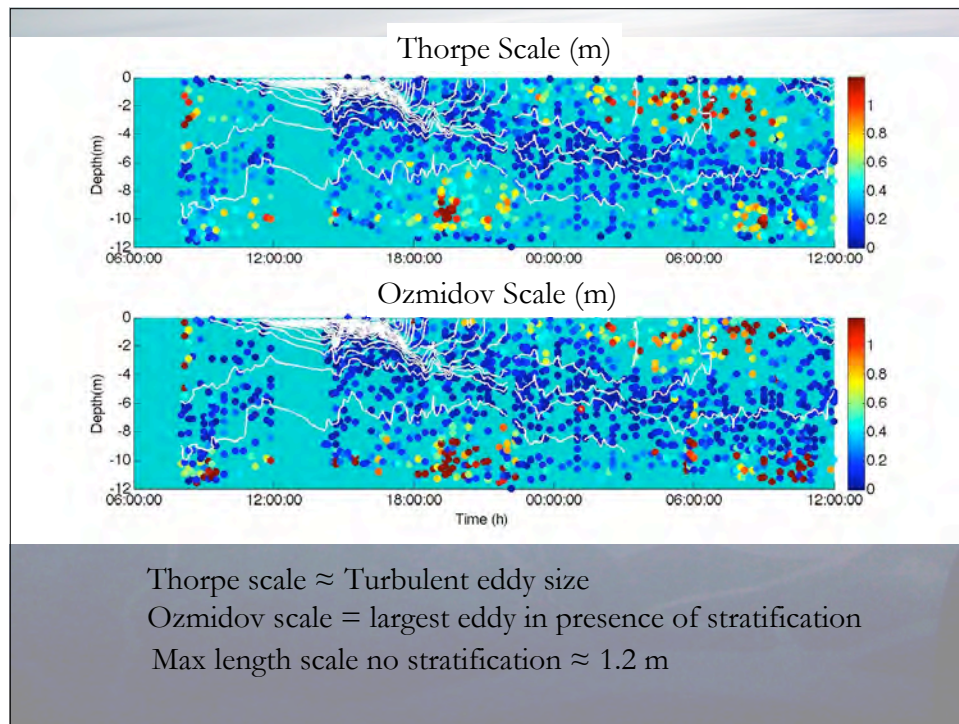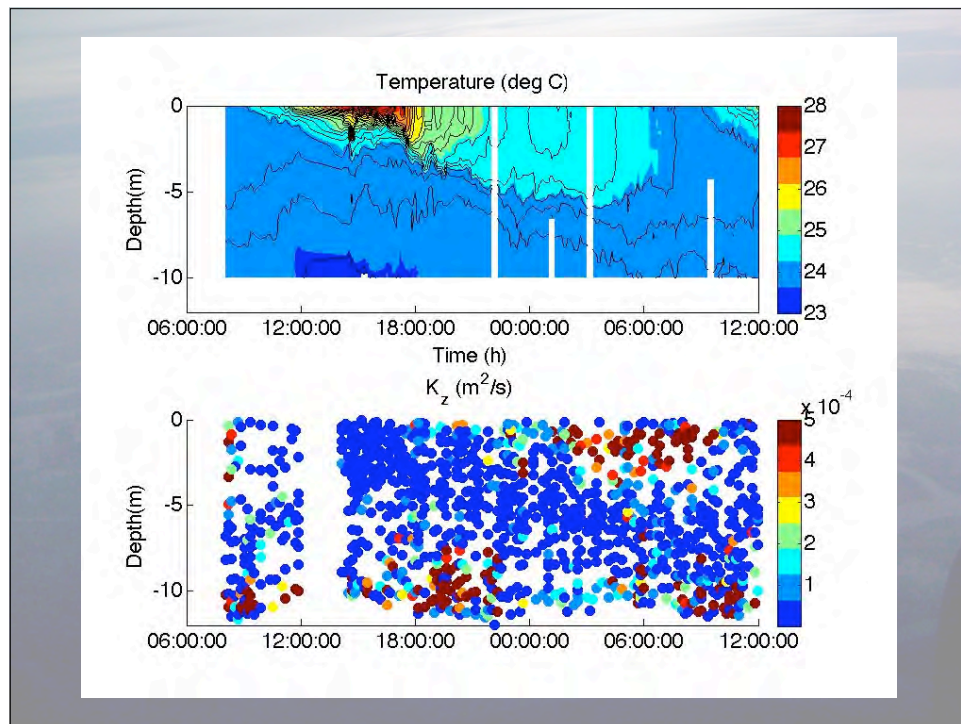
Summary

- Even "weak" thermal stratification can have a dramatic effect on vertical mixing
- Much of water column has turbulence controlled by buoyancy
- Phasing of tides and heating leads to sheared residual flow even without baroclinic pressure gradient

Why this might be tricky to model

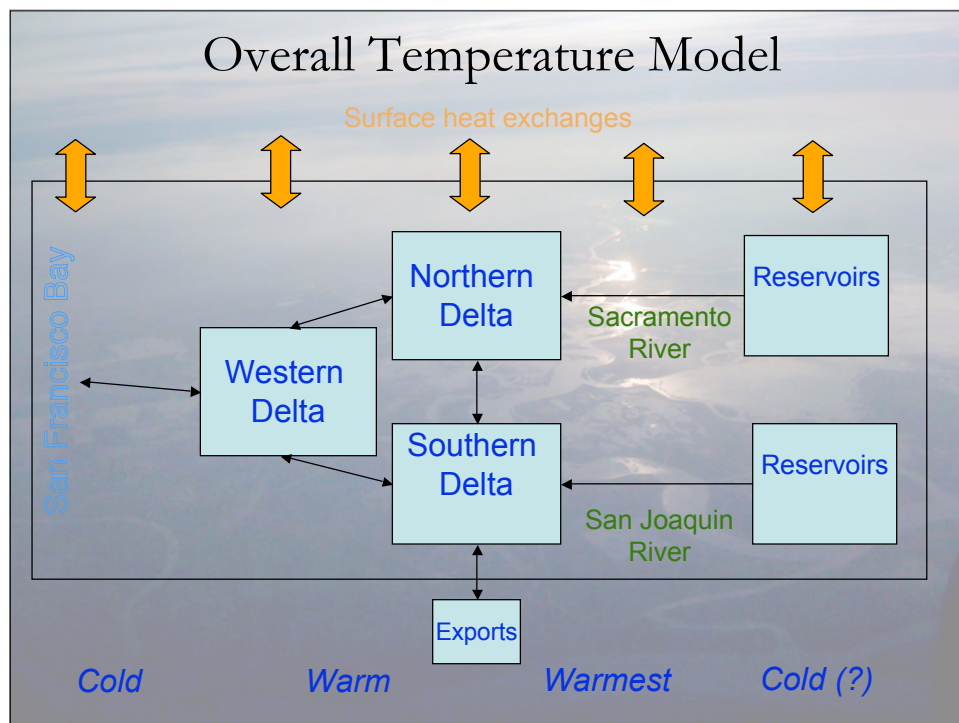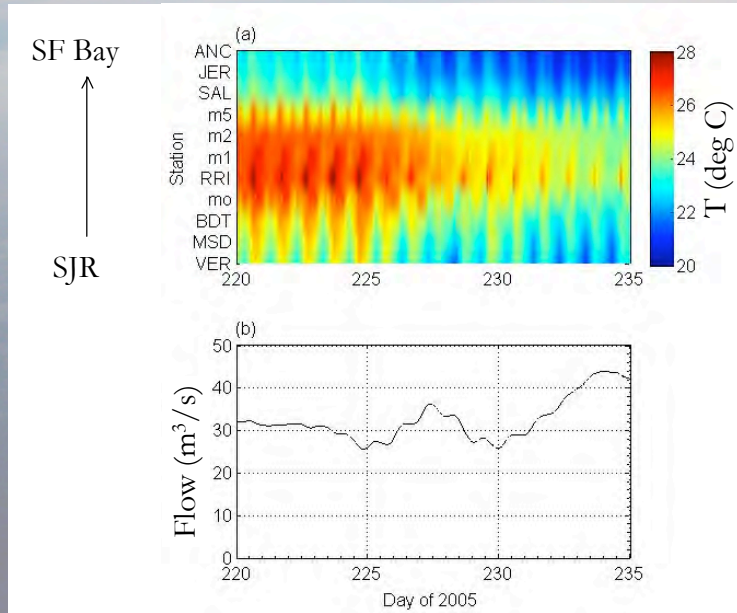- Stratification effects on turbulence is one of the principal unsolved problems in CFD/Fluid mechanics

Overall Temperature Model

Surface heat exchanges

San Francisco Bay

Northern Delta

Western Delta

Southern Delta

Reservoirs

Sacramento River

Reservoirs

San Joaquin River

Exports

Cold   *Warm*   *Warmest*   *Cold (?)*

Temperature variability San Joaquin/DWSC

2004 Spatial structure

Surface heat exchanges

Q_0 Q_{sens} Q_{lat} Q_{lw} Q_{sw}

source: Stacey and Monismith 2008 DRERIP
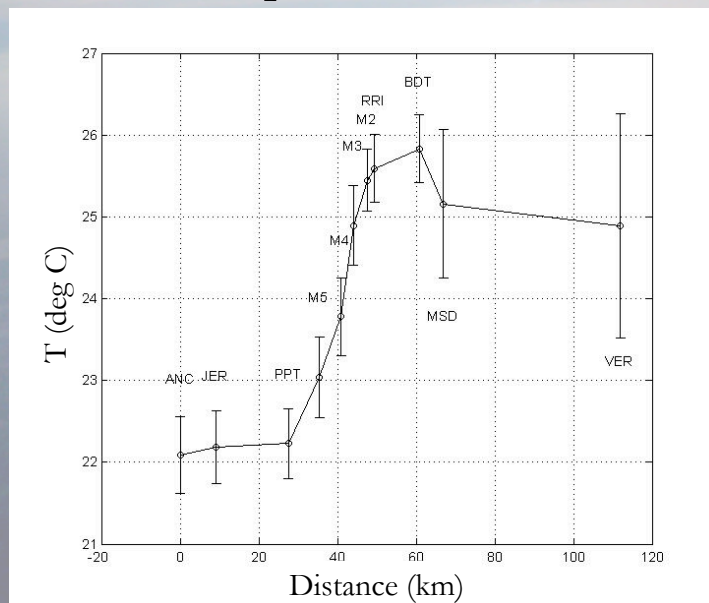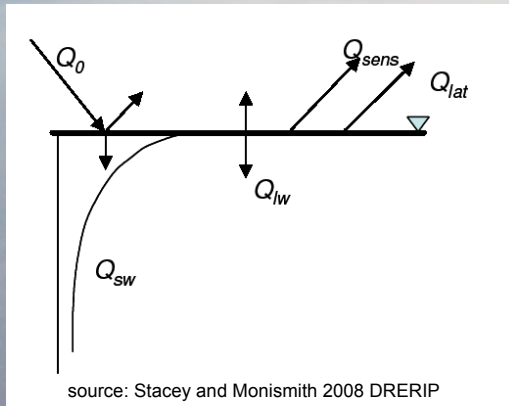
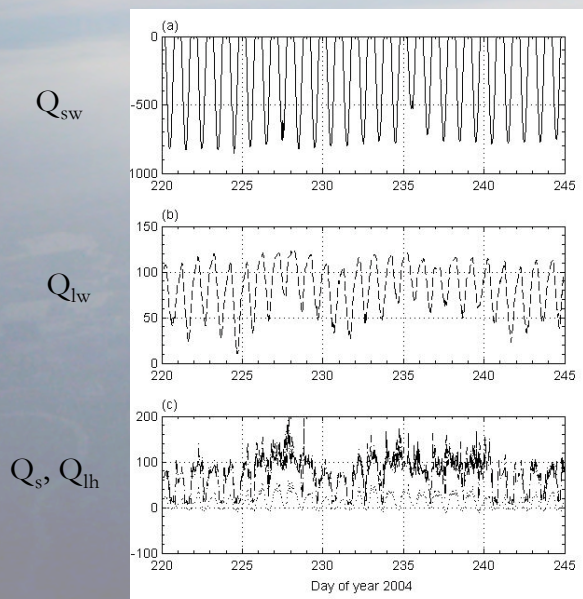Q_{sw} = shortwave - measured, corrected for albedo.
Q_{lw} = net longwave - calculated from T_w and T_a, needs cloudiness, can be measured
Q_{sens} = calculated from U_a, T_a, and T_w
Q_{lat} = calculated from U_a, T_a, T_w, Rh_a

U_a = windspeed, T_a = air temperature, T_w = water surface temperature, Rh_a = relative humidity of air

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SJR 2004 Heat fluxes

Q_{sw}

Q_{lw}

Q_s, Q_{lh}

Source:

Manteca CIMIS

M2

M2/Port of Stockton

First law of Thermodynamics applied to a water column in the San Joaquin

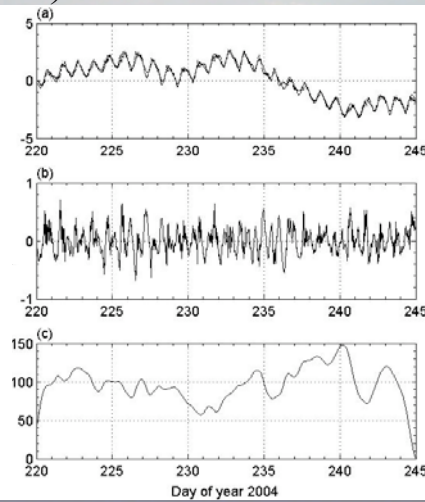$$I = \frac{d}{dt}\left(\int_0^H \rho c_p T\, dz\right) = -\left(Q_0(1-a) + Q_{lw} + Q_s + Q_{lh}\right)$$

I
(GJ m^{-2})

$I_{obs} - (I_{1D} + I_{corr})$
(GJ m^{-2})

Q_{corr}
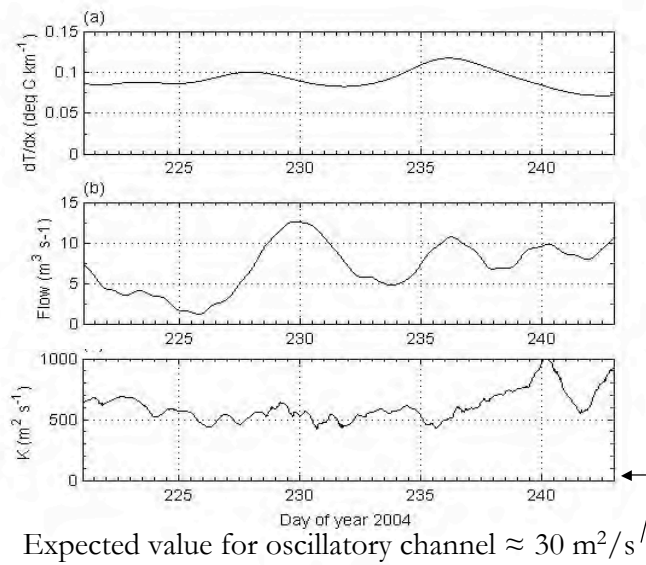(W m^{-2})

Day of year 2004

Correction heat flux calculated as dispersion coefficient

Subtidal model of cross-sectionally averaged temperature including river flow Q_f and dispersion with dispersion coefficient K

$$A(x)\frac{\partial T}{\partial t} - Q_f\frac{\partial T}{\partial x} + \frac{W\sum Q_{surf}}{\rho c_p} = \frac{\partial}{\partial x}\left(K(x)A(x)\frac{\partial T}{\partial x}\right)$$

Measure/Calculate   "Correction"

Results: 2004

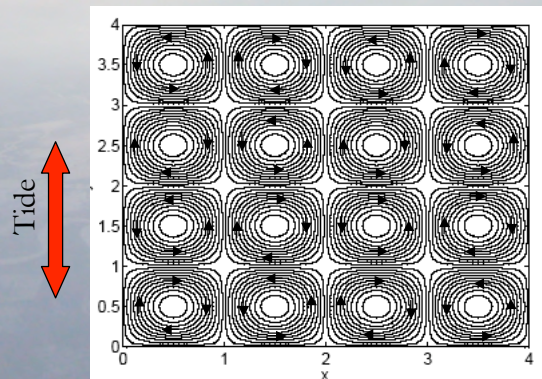Expected value for oscillatory channel ≈ 30 m²/s

Why so dispersive?

The Delta

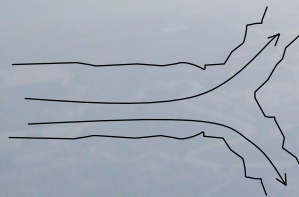Idealized periodic eddy field

Tide

Ridderhinkof and Zimmerman (1992)

Energetic tides over mean flow field w. divergence pts.
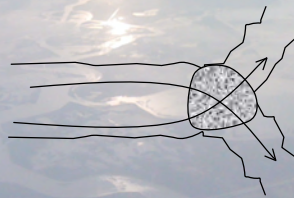produces chaotic, large dispersion

Why this might be tricky to model

- Large dispersion coefficient probably reflects effects of junctions at scale of whole Delta
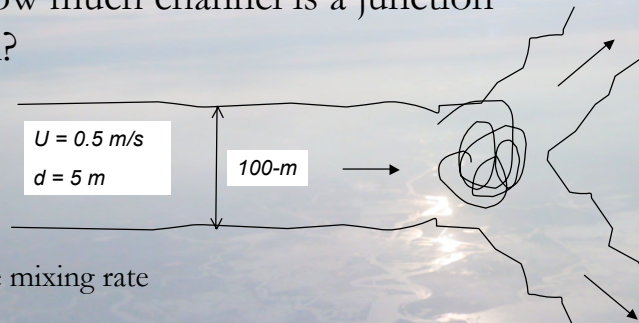- Does this depend on getting junction flows correct?

Junctions

Streamline following   Complete mixing at junction

Q: How much channel is a junction worth?

U = 0.5 m/s
d = 5 m

100-m

Transverse mixing rate

$$\varepsilon_t \approx C_D^{1/2} U H = 0.13 \, m^2 s^{-1}$$

Transverse mixing distance

$$L_m \approx 0.4 \frac{W^2}{\varepsilon_t} U \approx 16 \, km$$

A: A lot of channel!

Turner Cut

1.6 km

San Joaquin R.

A typical channel…

Fortran PTM (V. Sridharan)

- DSM PTM coded in Fortran - (intended for use with LSU/SFSU Delta Smelt model)
- Differences: Vertically variable mixing, RK4 time advancement, junction behavior
- For 2 channel junctions: no mixing - preserve position in channel
- For 3 channel junctions: follow streamlines or complete mixing
- For 4+ channels junctions: We are open to suggestions

Results
(November 1996)

Particles released at Jersey Island

Streamlines

Randomizing
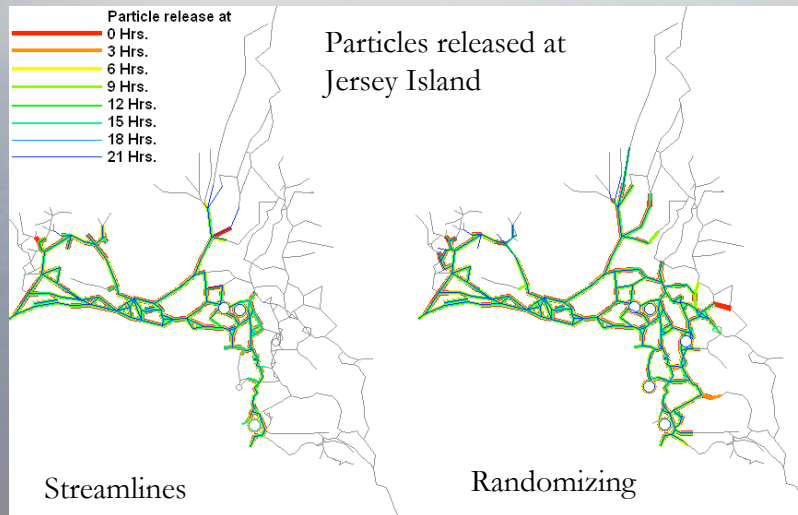
Particles released at Jersey Island:
Times are phase of tide of release
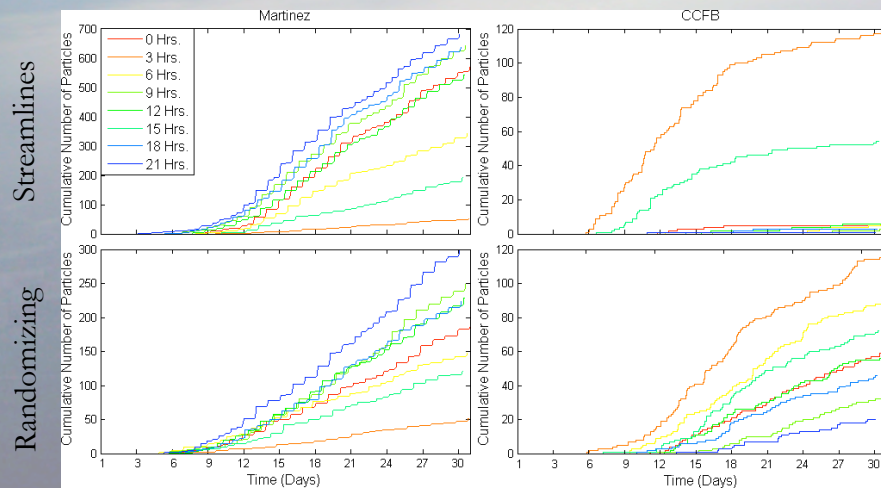
The two approaches give different results

Why this might be tricky to model

- Details of junction flow involve complex 3D circulation, possibly including non-hydrostatic pressures
- Details of secondary flows not done well yet in "normal" 3D models, tough even for high resolution models
- High resolution 3D models are slow

Thanks

Moorea (Not the Delta)